The University of New Mexico

Department of Electrical and
Computer Engineering
Room 125, EECE Building
Albuquerque, NM 87131-1356
Telephone (505) 277-2436
FAX (505) 277-1439

01 February 1999

DTIC-OCP
8725 John J. Kingman Road
Suite 0944
Fort Belvoir, VA 22060-6218

Dear Madam/Sir:

Per contractual requirements I am enclosing two copies of a final technical report on AFOSR Grant F49620-96-1-0379, both with a completed SF-298.

Thanks for your assistance with this matter.

Sincerely,

Edl Schamiloglu

Edl Schamiloglu
Associate Professor, EECE
Regents' Lecturer
Director, EECE Pulsed Power & Plasma Science Laboratory
505.277.4423 (Voice), 505.277.1439 (FAX)
`edl@eece.unm.edu`
`http://www.eece.unm.edu/faculty/edl/`

Copy:
AFOSR/PKA
810 N. Randolph St.
Arlington, VA 22203

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
02/01/99

3. REPORT TYPE AND DATES COVERED
Final Technical Report, 08/01/96/-12/31/98

4. TITLE AND SUBTITLE
A Versatile High-Power Laser System for High Spatial Resolution Nanosecond Plasma Diagnostics in Electron-Beam Driven High Power Microwave Sources

5. FUNDING NUMBERS
F49620-96-1-0379

6. AUTHORS
E. Schamiloglu

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of New Mexico
Department of Electrical and Computer Engineering
125 EECE Building
Albuquerque, NM 87131

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
801 N. Randolph Street
Room 732
Arlington, VA 22203

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
DURIP Grant linked to parent MURI Grant.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unlimited Distribution

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of the acquired instrumentation was to perform high spatial resolution and nanosecond time resolution plasma diagnostics in intense electron beam-driven high power microwave (HPM) sources to better understand the "pulse shortening" problem. We have thus performed the first laser interferometry measurement inside a high power backward wave oscillator (or any other intense beam-driven HPM source for that matter) during the course of microwave generation reported in the literature. Line-integrated electron densities between 9 x 10^15 and 2 x 10^16/cm^2 for microwave powers beween 20 and 120 MW have been measured. The two main sources of the measured electron density are postulated to be i) plasma generated from the cutoff neck due to beam scrape off and, ii) material removed and ionized from the slow wave structure walls during microwave generation. A catastrophic microwave discharge results in termination of subsequent microwave generation. Novel modifications to the inlet of the slow wave structure in intense beam-driven backward wave oscillators are suggested as a result of this research.

14. SUBJECT TERMS
High Power Microwaves (HPM), Pulse Shortening, Plasma Diagnostics, Laser Interferometry

15. NUMBER OF PAGES
7

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassifed

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-1
298-102

The University of New Mexico

Pulsed Power and Plasma Science Laboratory

DURIP-96 FINAL REPORT

A Versatile High-Power Laser System for High Spatial Resolution Nanosecond Plasma Diagnostic in Electron-Beam Driven HPM Sources

(Grant No. F49620-96-1-0379)

01 February 1999

Submitted by:

Edl Schamiloglu — Principal Investigator
Associate Professor and *Regents' Lecturer*
Department of Electrical and Computer Engineering
University of New Mexico
Albuquerque, NM 87131
Tel: (505) 277-4423
Fax: (505) 277-1439
e-mail: edl@eece.unm.edu

Abstract

This final report describes the acquisition and implementation of instrumentation purchased under the auspices of the FY'96 DURIP program. All of the laser and optical instrumentation have been purchased, installed, and used to measure plasma during the course of microwave generation in a high power backward wave oscillator (BWO) experiment. The results of this measurement have been documented in a journal publication that was included in the appendix of the Technical Progress Report dated 5 August 1998. The one outstanding acquisition as of the most recent progress report was the "educational reltron" high power microwave (HPM) source that was designed in conjunction with Titan Advanced Innovative Technologies (Albuquerque, NM). This final item was delivered in January 1999 and is now undergoing initial trials. It is anticipated that the educational reltron source will be utilized in classroom instruction at the graduate level in the 1999-2000 academic year.

The purpose of the acquired instrumentation was to perform high spatial resolution and nanosecond time resolution plasma diagnostics in intense electron beam-driven high power microwave (HPM) sources to better understand the "pulse shortening" problem.. We have thus performed the first laser interferometry measurement inside a high power backward wave oscillator (or any other intense beam-driven HPM source for that matter) *during the course of microwave generation* reported in the literature. Line-integrated electron densities between 9 x 10^{15} and 2 x 10^{16}/cm^2 for radiated microwave powers beween 20 and 120 MW have been measured. The two main sources of the measured electron density are postulated to be i) plasma generated from the cutoff neck due to beam scrape off and, ii) material removed and ionized from the slow wave structure walls during microwave generation. A catastrophic microwave discharge results in termination of subsequent microwave generation.

Description of Instrumentation

The instrumentation that was proposed to purchase were:

1. Coherent Inc. Infinity Pulsed Nd:YAG Laser System (this has been purchased, installed and used in our laboratory).
2. Burleigh Inc. PLSA Pulsed Laser Spectrum Analyzer and computer for operation (this has been purchased, installed, and used in our laboratory).
3. Newport Corp. optical workstation, components, and projects kits for educational component of award (this has been purchased, installed, and used in our laboratory).
4. Titan Advanced Innovative Technologies Educational Reltron High Power Microwave Source. (This has been constructed, delivered, and installed in the University of New Mexico EECE Department's Pulsed Power and Plasma Science Laboratory.)

Photographs of the equipment described above (excluding the reltron source) can be found at our website www.eece.unm.edu/muri98/punm1.htm and subsequent images. The balance sheet indicating the instrumentation acquisition dates is presented below.

Schamiloglu 3-47051 AFOSR (DURIP)

LINE	DATE	DESCRIPTION	DOCUMENT PR.PO.SPO.CR.INV	DEBIT	CREDIT	BALANCE	ROT DATE
6500	08/01/96	Equipment	Budget 113/738-4575		$141,087.00	$141,087.00	7
6500	08/22/96:09/10/96	Coherent/YAG Laser Sys.11/26/96	pr430897,po756635	$105,000.00		36,087.00	9/12
6500	09/16/96:09/23/96	Burleigh Inst/PLSA, 01/03/97	pr430900,po766012	17,532.10		18,554.90	9/1
6500	09/04/96:10/15/96	Newport Corp/optics...,12/23/96	pr430902,po766614	18,777.22		(222.32)	10/2
6500	04/25/97	Transfer overage to 1-17523	j e pdg		222.32	0.00	
--						-----	
gh, 11/21/97				Total Remaining:		$0.00	
pm, 12/14/98						=====	

Schamiloglu 1-17523 Cost share for 3-47051 AFOSR (DURIP)

LINE	DATE	DESCRIPTION	DOCUMENT REFERENCE #s	DEBIT	CREDIT	BALANCE	ROT DATE
0905	07/01/97	Balance Forward	r o t		$19,985.05	$19,985.05	7
0914	08/01/96	Allocations	Budget 113/738-4575	$25,000.00		($25,000.00)	xx
6500	08/01/96	Equipment	Budget 113/738-4575		$20,000.00	$20,000.00	xx
6500	09/23/97;10/02/97	Titan Rsch/reltron system, pd 01/13/99	pr464849,po775957	20,000.00		0.00	10/?
6500	09/15/97	Overage on 3-47051	j e pdg	222.32		(222.32)	
6510	08/01/96	Computer Equipment	Budget 113/738-4575		$5,000.00	$5,000.00	xx
6510						5,000.00	
--						----------	
gh, 01/13/99				Total Remaining:		($237.27)	
pm, 01/22/99						========	

Scientific Accomplishments using Instrumentation

Laser interferometry is used for the first time to measure plasma electron density along the slow wave structure (SWS) wall during microwave generation in a vacuum, long pulse, high power backward wave oscillator (BWO). The University of New Mexico long pulse backward wave oscillator, which displays the characteristic "pulse shortening" phenomenon, is investigated in these studies. Although pulse shortening is observed across a wide class of high power microwave (HPM) devices, its origin is not definitively understood. Many hypotheses suggest that the unintentional introduction of plasma into the interaction region near the walls of the SWS is one of several likely causes of pulse shortening in intense beam-driven slow wave devices. We have measured the line-integrated, temporally resolved plasma density between an intense, relativistic, annular electron beam and SWS walls for a variety of radiated microwave peak power levels. Line-integrated electron densities $<n_eL>$ between 9 x 10^{15} and 1.4 x 10^{16}/cm^2 for radiated microwave powers between 20 and 120 MW have been measured. The two main sources of the measured electron density are postulated to be i) plasma generated from the cutoff neck due to beam scrape off, and ii) material rmoved and ionized from the SWS walls during the course of microwave generation.

We summarize the scientific accomplishments by excerpting figures from our article *F. Hegeler, C. Grabowski, and E. Schamiloglu, "Electron Density Measurements During Microwave Generation in a High Power Backward-Wave Oscillator," IEEE Trans. Plasma Sci., vol. 26, pp. 275-281, 1998.* Complete details can be found in the article and references therein.

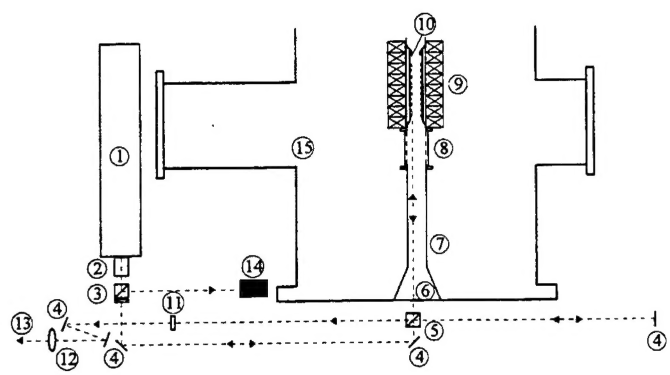


Fig. 2.[1] Optical arrangement of the Michelson laser interferometer. 1) 25 mW HeNe laser. 2) 3× beam expander. 3) Polarizing beamsplitter and quarter-wave plate. 4) Dielectric HeNe laser mirror. 5) Nonpolarizing beamsplitter. 6) Optical window enclosed by Mylar. 7) Conical horn antenna. 8) Electron beam dump. 9) SWS encircled by magnetic field-producing solenoids. 10) Mirror in the SWS. 11) Laser line filter. 12) Lens. 13) Toward laser detector. 14) Laser beam dump. 15) Vacuum vessel of the BWO.

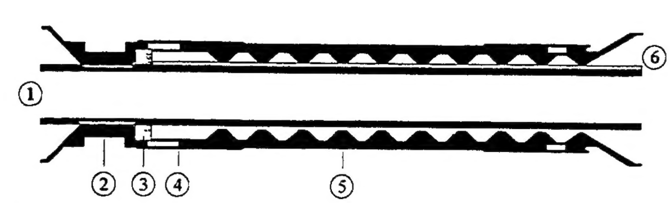
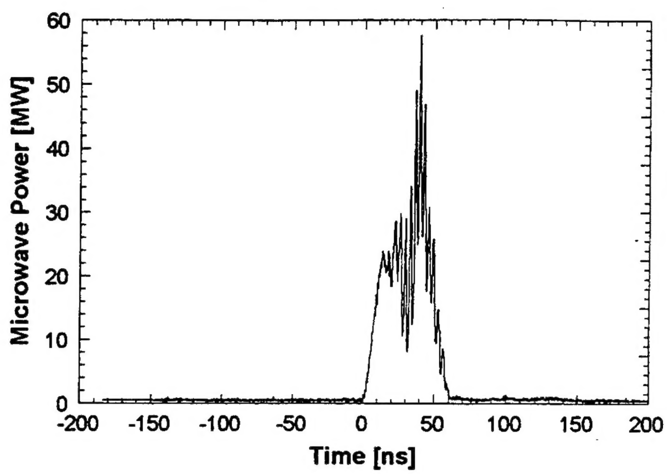
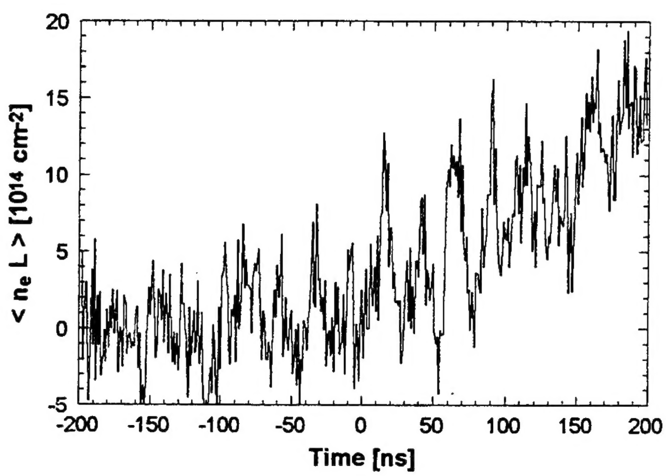


Fig. 3. Configuration of the SWS. 1) Electron beam. 2) Cutoff neck. 3) Gold coated stainless steel mirror ring. 4) 19 mm long spacer. 5) 10 ring periodic structure. 6) Location of the laser beam.



(a)



(b)

Fig. 7. Typical results of (a) the microwave signal and (b) the early phase of the line-integrated plasma density (i.e., phase I plasma).

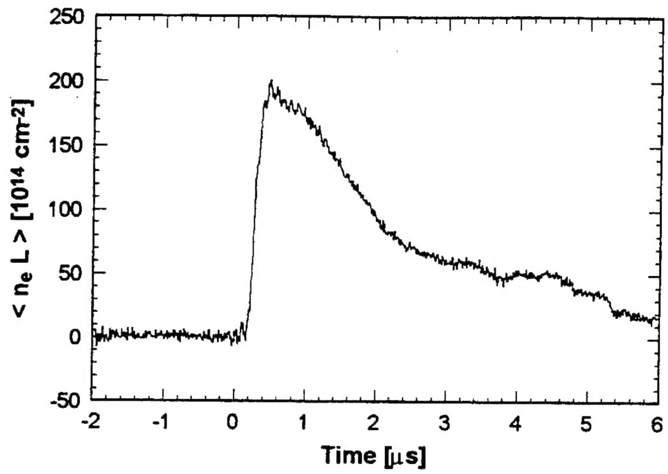


Fig. 8. Typical line-integrated plasma density signal on a longer time scale.

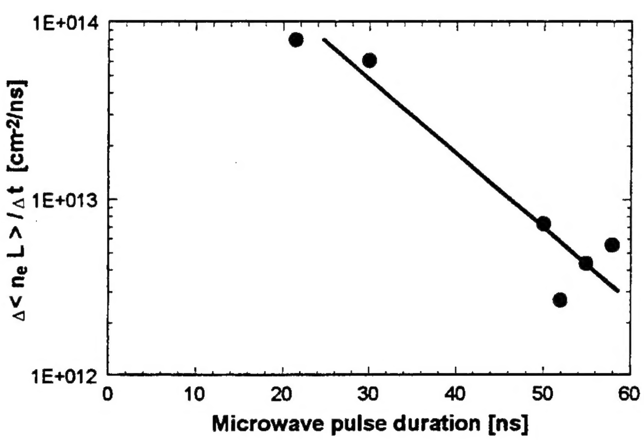


Fig. 9. Slope of the initial linearly rising part of the line-integrated plasma density, as a function of the microwave pulse duration. The pulse duration is measured at the base at the 10% points of its maximum pulse amplitude.

Students Trained using Instrumentation

The following postgraduate scientists utilized this instrumentation:

1) Dr. Frank Hegeler, Research Assistant Professor
2) Dr. Naz Islam, Research Associate Professor

The following graduate students utilized this instrumentation as part of their research:

1) Chris Grabowski (Ph.D. student, graduate 1998)
2) Gregory Todd Park (M.S. student, to graduate 1999)
3) Robert Wright (Ph.D. student, to graduate 1999)

The following undergraduate students utilized this instrumentation as part of their training as undergraduate research assistants in the Pulsed Power and Plasma Science Laboratory:

1) Tony Peredo (sophomore in the Electrical and Computer Engineering Department)
2) Kelly Hahn (senior in the Electrical and Computer Engineering Department)

Finally, portions of the laser instrumentation, as well as the Educational Reltron HPM source will be used as part of EECE 553L, *Experimental Plasma Physics and Pulsed Power*, a graduate level course to be offered in academic year 1999-2000.

Future Use of Instrumentation

In the next series of experiments, a modified inlet to the slow wave structure in our long pulse backward wave oscillator experiment will be used. This modified inlet is a Bragg Reflector and it is postulated to minimize electron beam "scrape-off," thereby minimizing unwanted plasma from being introduced into the slow wave structure system. Laser interferometry of this new configuration will be critical in assessing the success of this modification.

An additional experiment is planned whereby the Nd:YAG laser will be utilized to selectively ablate material from specific sections along the slow wave structure during microwave generation. This material ablation will then be correlated with pulse shortening, as well as the laser interferometric measurements.

Presentations and Publications Describing the Utilization of this Instrumentation

The utilization of the instrumentation acquired under this DURIP grant is described in one journal publication, two conference publications, and four conference presentations, as indicated:

1) F. Hegeler, C. Grobowski, and E. Schamiloglu, "Initial Measurements of Wall Plasma Using Laser Interferometry in a Long-Pulse Backward Wave Oscillator," Bull. Am. Phys. Soc. **42**, 1868 (1997).
2) F. Hegeler and E. Schamiloglu, "Laser Interferometry in a Relativistic Backward Wave Oscillator (Invited Presentation), IEEE International Conference on Plasma Science (Raleigh, NC, 1998).
3) E. Schamiloglu, F. Hegeler, C. Grabowski, and D. Borovina, "Recent Results from a Long Pulse, Relativistic Vacuum and Plasma-Filled Backward Wave Oscillator Experiment," to appear in *Proceedings of Beams '98* (Haifa, Israel, June 1998).
4) F. Hegeler, C. Grabowski, and E. Schamiloglu, "Electron Density Measurments During Microwave Generation in a High Power Backward-Wave Oscillator," IEEE Trans. Plasma Sci., vol. 26, pp. 275-281, 1998.
5) F. Hegeler, E. Schamiloglu, S. Korovin, and V. Rostov, "Improved Beam Inlet Design in a Relativistic Backward Wave Oscillator for Pulse Lengthening Studies," Bull. Am. Phys. Soc. **43**, 1839 (1998).
6) F. Hegeler, E. Schamiloglu, S.D. Korovin, and V.V. Rostov, "Recent Advances in the Study of a Long Pulse Relativistic Backward Wave Oscillator," submitted to the 12th IEEE International Pulsed Power (Monterey, CA, July 1999).
7) F. Hegeler, E. Schamiloglu, S.D. Korovin, and V.V. Rostov, "Progress on Pulse Lengthening of a Relativistic Backward Wave Oscillator," submitted to the IEEE International Conference on Plasma Science (Monterey, CA, June 1999).